Contribution of windfarms to ancillary services

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CONTRIBUTION OF WIND FARMS TO ANCILLARY SERVICES

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SUMMARY

In the last decade, wind energy has experienced a substantial growth in Europe with an increase in generation capacity from 2.5 GW in 1995 to 34 GW at the end of 2004. This increase has raised new problems and constraints which led system operators, electric utilities, governments or regulatory boards to define technical requirements for the grid connection of wind farms and more generally of distributed generation (DG) units. At first, the requirements for wind farms were rather "soft" (at least softer than for other DG units) and were mainly intended to limit the "disturbances" caused by wind energy on power quality and grid operation. But with the ever increasing development of wind power, the impacts on the grids become more and more significant leading to the definition of more and more "severe" requirements. In particular, wind farms (WF) are now more and more often asked to provide some sort of ancillary services such as contribution to voltage/reactive power control and frequency/active power control. This paper focuses on the possible provision of such ancillary services by wind farms. Regarding reactive power and voltage control:

- Doubly-fed Induction Generators (DFIG) and Synchronous or Induction Generators with full power electronics interfaces (SIG) can have reactive power control capabilities (both in production and absorption) depending on the rating of their power electronics converters. These capabilities (characterized by a fast dynamic response) can be used to perform voltage control. Moreover, if required, external reactive power compensation devices may also be installed.
- Classical Induction Generators (CIG) do not have such reactive power control capabilities and therefore require external devices for reactive power and voltage control.
- Simulations carried out show that WFs with voltage control capabilities can significantly sustain the network voltage in case of grid events and thus may efficiently support the power system stability.

Regarding frequency control: the results show that when the Wind Turbine Generator (WTG) is fully loaded (maximum active power generation), appropriate use of the pitch control may enable the WTG (DFIG, SIG or CIG) to contribute to frequency control. In case of partial load, the contribution to frequency control can be achieved either by "disoptimizing" the wind energy conversion by means of the pitch control, or by setting a non-optimal rotor speed for DFIG or SIG. However, a judicious way to use variable speed generators may also be to operate them as inertial flywheels.

KEYWORDS

Frequency control, ancillary services, active power control, reactive power control, voltage control, wind farm

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1. Introduction

In the last decade, wind energy has experienced a substantial growth in Europe with an increase in generation capacity from 2.5 GW in 1995 to 34 GW at the end of 2004, with leading countries such as Germany, Spain, Denmark. This increase raised new problems and constraints on distribution and transmission power systems which led system operators, electric utilities, governments or regulatory boards to define technical requirements for the grid connection of wind farms and more generally of distributed generation (DG) units. At the beginning, the technical requirements for wind farms were "softer" than for other "classical" DG units: either specific rules were defined or the existing rules for DG were adapted, or in some cases, exemptions applied. But with the ever increasing development of wind power, the impacts on the grid become more and more significant leading to the definition of more and more "severe" requirements. At first, the requirements have evolved in order to limit the disturbances of wind energy on system operation (e.g. definition of Fault Ride Through requirements). Now wind farms (WFs) are more and more often asked to provide some sort of ancillary services. This paper focuses on the possible contribution of wind farms to ancillary services and more specifically to:

- voltage control and reactive power compensation,
- frequency regulation.

2. Wind energy and ancillary services

2.1. Impact of wind energy on ancillary services

Ancillary services (AS) have been and are still provided for the major part by large centralized power plants connected to the transmission network. The characteristics of ancillary services and of their provision were devised in this context. With the present evolution of power systems and in particular with the advent of DG and wind energy on distribution (and transmission) networks these characteristics will probably need to be adapted, extended or revised. Different issues are raised [1-2].

First, power systems and in particular distribution networks were initially designed to operate with unidirectional power flows (from the centralized power plants to the loads). With the advent of DG and wind farms, this is no more the case. Depending on the technology used, this has raised new problems and constraints at different levels: modification of the power flows, of the voltage profile, of the steady-state and short-circuit currents, possible degradation of the quality supply, interaction with the protection system, degradation of network stability, etc. This has to be taken into account in the way ancillary services are provided or should be provided.

Then, a large development of DG of stochastic nature like wind energy, is expected to cause larger imbalances between generation and consumption thus leading to an increased demand in active power reserves. For example it is estimated that a 10 000 MW wind power penetration in the UK would need a 160 MW additional reserve capacity which corresponds to 1.6 % of the installed wind power capacity [3]. In Germany, to balance unforeseen variations in wind power, the need of additional reserve is expected to reach 9 % of the installed wind power capacity by 2015 [4].

Large amounts of DG or wind energy on power systems lead to reduce the share of centralized power plants (CCP) in the balance between generation and consumption. However, due to the trend of load increase on the European grid, the development of DG and wind energy does not necessarily means a decrease of the contribution of centralized power plants in absolute value. Nevertheless, the contribution of both distributed and centralized generation units to AS has to be revised and an efficient and economical way to provide AS needs to be found.

2.2. Needs for ancillary services from wind farms

Ancillary Services (AS) may be divided in two main categories [1-2]:

- local AS such as voltage control and reactive power supply, which have to be provided locally (or regionally) where they are needed,

- system-wide AS such as frequency control and active power reserves, which may be provided anywhere in the power system.

Local AS have to be performed by local means. Therefore distributed generation (DG) and WFs in particular may be and are sometimes already requested to contribute. More specifically, there is a need of contribution in terms of:

- primary voltage control or reactive power supply. This is a local automatic control which can take different forms depending on the size and capabilities of the DG units: constant reactive power, reactive power control, power factor control, or actual voltage control.
- Secondary voltage control, presently required only for large DG units connected to the transmission grid. Secondary voltage control is a centralized automatic control which coordinates the actions of generating units in order to manage the flow of reactive power within a predefined voltage zone. The use of a dedicated communication system is required. For high DG penetration levels, the contribution of smaller generating units (even those connected to the medium voltage level) might be required. However, the implementation of secondary voltage might then need to be revised to take into account the specificities of distribution networks (e.g. radial topology, etc).
- Network restoration. With high penetration levels of DG, centralized power plants may not be able to efficiently restore the whole power system since they will contribute to only a part of the consumption. Therefore DG units, depending on their size, may be required to participate. Again, for this purpose, appropriate communication means and coordination strategies will have to be devised and used. Due to the stochastic nature of wind energy, it is difficult for WFs to participate to network restoration without storage or coordination with other DG units.
- System stability. Firstly, at the local level, support of system stability implies that DG units keep their own stability and stay connected to the network in disturbed situation. Secondly, support of system stability may involve a contribution to the voltage control and the provision of reactive power in order to prevent voltage dip to propagate and therefore help to maintain stability at a regional level.

System-wide AS, as mentioned above, may be provided (almost) everywhere on the power system as long as no constraint is violated due to this provision (e.g. maximum current limits on transmission lines). Typically, primary frequency control, secondary frequency control and tertiary frequency control are system-wide ancillary services.

- Primary frequency control is a fast automatic control which delivers the appropriate amount of primary reserve power in a few tens of seconds in order to restore quickly the load-generation balance for power system security reasons. This control counteracts frequency variations and is indispensable to the network stability.
- Secondary frequency control is a centralized automatic control which starts acting within 30 seconds (within the UCTE). It delivers secondary reserve power in a few minutes in order to bring back the frequency to its target value, and maintains the exchanges between the interconnected networks in compliance with the interchange program.
- Tertiary frequency control is a manual control which starts acting in about fifteen minutes. It adjusts production and consumption taking into consideration economic criteria and congestion problems. It enables to restore the primary and secondary power reserves, and to bring back the frequency and the interchange programs to their target if the secondary control is unable to perform this task.

Contribution to system stability is also a system-wide issue as far as active power provision or active power oscillations are concerned. Typically, DG units and wind farms in particular are presently not requested to participate in such system-wide AS (except on islanded power systems). However, with the increased development of wind energy, transmission system operators begin to define some requirements in some countries in terms of active power control of wind farms. With higher and higher penetration levels of DG, the definition of requirements may be expected in terms of contribution to active power reserves (at least primary frequency control reserve) and (some kind of) frequency control. For large DG unit, contribution to load follow and secondary control may even be envisaged, implying the use of appropriate communication means and coordination strategy.

3. Voltage regulation and reactive power compensation with wind energy

This section deals with the capability of wind farms to participate to voltage regulation and reactive power compensation. The following topics are presented:

- grid connection requirements on French distribution networks. At the end of 2005, all the wind farms in metropolitan France were connected only to distribution networks, so only this case is taken into account in this paper,
- wind farm capabilities regarding reactive power and voltage control,
- choice of a voltage regulation for wind farms on medium voltage (MV) networks (20 kV voltage level in France) and the resulting impact on the network.

A new "energy policy law" was promulgated on July 13, 2005 in France. With this new law, the purchase obligation for wind energy is no more limited to wind farms smaller than 12 MW as before but is now applicable only for wind farms located in "wind power development areas". These areas are defined by the prefects (regional authorities) on proposals coming from the town councils. The "old" system with a purchase obligation for wind farms smaller than 12 MW will still be applicable in parallel for two years. Furthermore, invitations to tenders for large onshore and offshore wind farms (larger than 12 MW) have been made by the French government and 8 projects have been accepted representing a total power of 330 MW. So, in the future, WF connections to the transmission network will come out since according to the French regulation, generation units larger than 12 MW have to be connected to the transmission grid. For these wind farms, the connection requirements to the transmission network will then have to be taken into account.

3.1. Grid connection requirements

In France, the technical requirements for the connection of generating units to mainland distribution networks are specified in decrees and ministerial orders [5-8]. Regarding voltage control and reactive compensation, the following requirements are defined:

Connection Level	Installed power of the WF	Connection conditions regarding voltage control and reactive power
LV	$P < 250$ kVA	No reactive power must be consumed
MV	$P \leq 1$ MW	Each generating unit shall be able to produce (at the machine terminals) reactive power up to 40% of its apparent nominal power Sn
	$1 \text{ MW} < P \leq 10$ MW	Each generating unit must be able to produce (at the machine terminals) at least 50% of Sn and to consume at least 10% of Sn. The WF shall be able to adjust the voltage control at the DNO's request.
	$10 \text{ MW} < P \leq 12$ MW	Each generating unit must be able to produce (at the machine terminals) at least 60% of Sn and to consume at least 20% of Sn. The WF shall be equipped with a voltage control system.

with LV for low voltage and DNO for Distribution system operator.

A specific rule applies for classical induction generators: their reactive power needs and the possibly required additional reactive power generation are provided by capacitor banks connected either to the producer's installation or to the HV/MV[1] substation. The reactive power produced by the capacitor banks at the DNO's request shall not exceed 0.4 Sn.

The value of the reactive power produced and the control mode (voltage, power factor or reactive power control) are determined by the distribution network operator in accordance with network operation requirements.

The choice of the value of the reactive power produced, the control mode and its characteristics can have an impact on flicker and voltage fluctuations, on voltage fluctuations at coupling and decoupling of the WF, on the dynamic behavior and stability.

[1] In France, HV levels are 400 kV, 225 kV, 150 kV, 90 kV and 63 kV voltage levels. The MV level is mostly 20 kV voltage level and sometimes 15 kV voltage level.

3.2. Voltage and reactive power control capabilities of wind farms

Voltage and reactive power control can be performed [9]:

- by the wind turbines generators themselves (see Section 3.2.1),
- and/or by additional devices located in the wind turbines or on the internal network of the wind farm (Section 3.2.2).

Note that, even if it is not the present practice in France due to the regulatory framework, the needs of the network regarding reactive power and voltage control might also be fulfilled by devices or other generating plants located in the vicinity of the connection point of the considered wind farm.

3.2.1. Wind turbine technologies

Wind turbine generators (WTG) could be divided into 3 main types:

- Classical squirrel cage induction wind turbine generator (CIG) directly connected to the grid (including induction WTG with dynamic slip control). These WTG only consume reactive power: from roughly 25% of nominal power at no load up to roughly 60% at full load. The reactive power consumption is directly linked to the active power production and the voltage value at the generator terminals. So no reactive power control nor voltage control is possible with this type of generator.
- Doubly-fed induction WTG (DFIG): induction generator with the rotor windings connected to the machine terminals through back-to-back power electronics converters. The reactive power capacity directly depends on the rating of the power electronics converters (usually from 10% to 30% of the WTG apparent power Sn). Depending on the wind turbine considered, reactive power ranges up to ± 0.3 Sn can be observed. The maximum reactive power that can be provided or consumed results from a current limit in the converters and therefore is further limited by the active power effectively produced. The time constant of the reactive power or voltage control can be as low as a few milliseconds.
- Synchronous or Induction WTG connected to the grid through back-to-back power electronic converters (SIG). This type of WTG can provide or consume reactive power depending on the rating of the converters. So if we consider a probable case of a converter designed at 110% of the nominal power, the reactive power capacity at full load and nominal voltage is ±0.45 Sn. Again, the time constant of the reactive power or voltage control can be as low as a few milliseconds.

3.2.2. Additional devices for reactive power and voltage regulation

Additional devices combined with wind farms can provide the required reactive power and voltage control capability either totally as in the case of CIG, or as a complement to the existing capability of the WTG technology used as in the case of DFIG and SIG.

Possible additional devices are:

- Static VAR Compensator (SVC): based on thyristor-controlled reactors, or thyristor-switched capacitors. The typical response time of a SVC is around 20 milliseconds.
- STATCOM: based on voltage sourced converters (VSC), it is a voltage source where the amplitude, phase and frequency are entirely controllable. The capacitor on the DC bus applies a DC voltage at the input of the inverter. The inverter output is connected to the AC grid via an inductance (generally a transformer). While adjusting the converter voltage in function of the network voltage, the converter can very quickly supply or absorb reactive power thanks to the control signals of the switches of the converter. The response time is mainly influenced by the switching frequency (typically 1 to 2 kHz), the size of the inductance, the measurement and calculation time. It can be as small as a few milliseconds.
- Synchronous Condenser: they are synchronous generators without prime mover, that can be controlled to absorb or provide reactive power and can perform a voltage control. They have been partly supplanted by static compensators.

Note that these additional devices for reactive power and voltage control can in specific cases provide the wind farm with a Fault Ride Through (FRT) capability (i.e. such that the wind farm will not disconnect in case of a voltage dip in the network).